

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 07 December 2005		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 01/01/2001-09/30/2005	
4. TITLE AND SUBTITLE An Analysis of Long-Range Acoustic Propagation Fluctuations and Upper Ocean Sound Speed Variability				5a. CONTRACT NUMBERS	
				5b. GRANT NUMBER #N00014-01-10313	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) John A. Colosi				5d. PROJECT NUMBER 13131300	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Ocean Physics and Engineering Dept. Woods Hole Oceanographic Institution 86 Water Street, MS #11 Woods Hole, MA 02543				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research, Ocean Acoustics				10. SPONSORING/MONITORING ACRONYM(S) ONR	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The objectives of this work were both observational and theoretical. Several low-frequency and broadband long-range transmission data sets in which data was obtained on long vertical receiving arrays were analyzed to quantify acoustic phase and intensity variability, as well as temporal and vertical coherence. One short range experiment (87 km) was also examined to quantify acoustic scattering over the first 2 upper turning points. In addition, analysis of oceanographic measurements of upper ocean processes quantified acoustic scattering structures. Coupled mode, Geometric (ray-based) and parabolic equation models were used to examine the underlying acoustic scattering physics.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON John A. Colosi
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19 b. TELEPHONE NUMBER (Include area code) (831) 656-3260

An analysis of long-range acoustic propagation fluctuations and upper ocean sound speed variability

John A. Colosi: PI

Woods Hole Oceanographic Institution, Applied Ocean Physics & Engineering Department,
Woods Hole, MA 02543

Current contact information:

Department of Oceanography, Naval Postgraduate School, Monterey CA 93943

Ph: 831-656-3260, FAX: 831-656-2712, E-mail: jacolosi@nps.edu

Award Number: N00014-01-1-0313

LONG-TERM GOALS

The long-term goals of this research are to understand the predictability limits of long-range acoustic transmissions, and to delineate the important environmental factors contributing to predictability.

OBJECTIVES

The objectives of this work were both observational and theoretical. Several low-frequency and broadband long-range transmission data sets in which data was obtained on long vertical receiving arrays were analyzed to quantify acoustic phase and intensity variability, as well as temporal and vertical coherence. One short range experiment (87 km) was also examined to quantify acoustic scattering over the first 2 upper turning points. In addition, analysis of oceanographic measurements of upper ocean processes quantified acoustic scattering structures. Coupled mode, Geometric (ray-based) and parabolic equation models were used to examine the underlying acoustic scattering physics.

RESULTS

Scientific results from this project can be found in 12 published journal articles (See below). Several highlights are noteworthy.

My colleagues and I were able to show that acoustic ray propagation through ocean internal waves can describe many of the observed wavefront features even though ray theory is a high frequency approximation which is susceptible to chaotic behavior. While ray theory did a good job on the geometry of the wavefront, results with regards to intensity variability were not as convincing. Therefore this project also set out to explore the effects of internal waves on acoustic mode propagation. Here we developed a stochastic coupled mode theory that does a great job at predicting the mean acoustic intensity. We are working on higher moments of intensity, and including broadband effects.

Using observations of upper ocean current shear and sound speed fluctuations I was able to demonstrate that acoustic scattering in the upper ocean may be strongly influenced by internal wave induced current shear. The observations were used in conjunction with ray theory for a moving ocean.

Using observations from 5 different experiments at frequencies of 28, 75, and 84 Hz, I quantified acoustic fluctuations in the finale of long range transmissions from the 3000-5000 km range. The finale was used because the signal to noise level was most favorable. The finale is a region of complex multipath interference and is thus the most unstable part of the wavefront. Using acoustic quantities like variance of phase, intensity, and coherence, I was surprised to find that the finale was relatively stable over short 20-40 minute observations times. These results give great hope to using other more stable regions of the wavefront for signal processing analysis.

Finally, using 75 Hz short range data (87 km) my graduate student and I were able to demonstrate the important mechanism of acoustic ray-internal wave resonance. This resonance occurs when the acoustic ray path is parallel to the internal wave crests.

PUBLICATIONS RESULTING FROM THIS PROJECT

- 1) M.G. Brown, J.C. Colosi, S. Tomsovic, A.L. Virovlyansky, M. Wolfson, and G.M. Zaslavsky, "Ray dynamics in ocean acoustics", J. Acoust. Soc. Am. V113(5), pp2533-2547, 2003.
- 2) F.J. Beron-Vera, M.G. Brown, J.C. Colosi, S. Tomsovic, A.L. Virovlyansky, M. Wolfson, and G.M. Zaslavsky, "Ray dynamics in a long range acoustic propagation experiment", J. Acoust. Soc. Am. V114(3), pp1226-1242, 2003.
- 3) J. A. Colosi, and A. B. Baggeroer, "On the kinematics of broadband multipath scintillation and the approach to saturation", J. Acoust. Soc. Am., V116(6), pp 3515-3522, 2004.
- 4) A. Fredricks, J. A. Colosi, J.F. Lynch, G. Gawarkeiwicz, C.S. Chiu, and P. Abott, "Analysis of multipath scintillations from long range acoustic transmissions on the New England continental slope and shelf", J. Acoust. Soc. Am., V117(3), pp1038-1057, 2005.
- 5) A. Morozov, and J. Colosi, "Entropy and scintillation analysis of acoustical beam propagation through ocean internal waves," J. Acoust. Soc. Am., 117(3), pp161-1623, 2005.
- 6) J.A. Colosi, A. B. Baggeroer, B. Cornuelle, M.A. Dzieciuch, W. Munk, P. Worcester, B. Dushaw, B. Howe, J. Mercer, R. Spindel, T. Birdsall, K. Metzger, and A. Forbes, "Analysis of multipath acoustic field variability and coherence in the finale of broadband basin-scale acoustic transmissions in the North Pacific Ocean", J. Acoust. Soc. Am, 117(3), pp1538-1564, 2005.
- 7) Baggeroer, A. B., E. Scheer, J. A. Colosi, B.D. Cornuelle, B.D. Dushaw, M. A. Dzieciuch, B.M. Howe, J. A. Mercer, W. H. Munk, R. C. Spindel, and P. F. Worcester, "Statistics and vertical directionality of low-frequency ambient noise at the North Pacific Acoustics Laboratory site", J. Acoust. Soc. Am., V117(3), pp1643-1665, 2005.

- 8) Vera, M. D., K. Heaney, J. A. Colosi, B.D. Cornuelle, B.D. Dushaw, M. A. Dzieciuch, B.M. Howe, J. A. Mercer, W. H. Munk, R. C. Spindel, and P. F. Worcester, ``The effect of bottom interaction on transmissions from the North Pacific Acoustic Laboratory Kauai source, '', J. Acoust. Soc. Am., V117(3), pp1624-1634, 2005.
- 9) Voronovich, A.G., V.E. Ostashev, J. A. Colosi, B.D. Cornuelle, B.D. Dushaw, M. A. Dzieciuch, B.M. Howe, J. A. Mercer, W. H. Munk, R. C. Spindel, and P. F. Worcester, ``Horizontal refraction of acoustic signals retrieved from North Pacific Acoustic Laboratory billboard array data'', J. Acoust. Soc. Am., V117(3), pp1527-1537, 2005.
- 10) Andrew, R. K., B. M. Howe, J. A. Mercer, J. A. Colosi, B.D. Cornuelle, B.D. Dushaw, M. A. Dzieciuch, B.M. Howe, J. A. Mercer, W. H. Munk, R. C. Spindel, and P. F. Worcester, ``Transverse horizontal spatial coherence of deep arrivals at megameter ranges'', J. Acoust. Soc. Am., pp1511-1526, 2005.
- 11) Lynch, J. F., J. A. Colosi, G. Gawarkiewicz, T. F. Duda, M. Badiy, B. Katznelson, J. E. Miller, and C.S. Chiu, "Inclusion of finescale coastal oceanography and 3-D acoustic effects into the ESME sound exposure model," IEEE J. Oceanic Eng., Special Issue on the Effects of Sound on the Marine Environment (ESME), in press, 2005.
- 12) J. A. Colosi, ``Geometric sound propagation through an inhomogeneous and moving ocean: Scattering by small scale internal wave currents'', J. Acoust. Soc. Am., in press, 2005.

In Preparation:

- 1) J.A. Colosi, J. Xu, and The NPAL Group, "Observations of upper ocean sound speed variability in the North Pacific Ocean", J. Acoust. Soc. Am.
- 2) J. Xu, and J. Colosi, ``Observations and modeling of single and double turning point acoustic scattering for 75 Hz sound transmission in the North Pacific Ocean'', J. Acoust. Soc. Am.

Conference Proceedings:

- 1) A. Morozov and J. Colosi, "Entropy of acoustical beams in a random ocean", IEEE Oceans Symposium, September 2003.